Seismic Noise Analysis System:

A Stand-Alone Software Package

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Abstract

In this USGS open-file report we detail the methods and installation procedures for a stand alone noise analysis software package that is based on the calculation of the distribution of power spectral density (PSD) using a probability density function (PDF). Following the successful implementation of the PDF Noise Analysis System, at both the IRIS DMC in Seattle, WA, and the ANSS DCC in Golden, CO, we will make the system available to the seismic community at large in a stand-alone form. This will allow users in the broader seismic community the opportunity to perform their own analyses on data sets not being held by either of these two data centers. Potential users might include regional earthquake monitoring network operators, IRIS PASSCAL experiment investigators and researchers and students interested in the quality and noise characteristics of a particular data set. Results from this noise analysis display the frequency dependent power distribution of the entire data set and are useful for characterizing the performance of existing broadband stations, for detecting operational problems, and for learning about sources of seismic noise within a data set.

This report is divided in two sections. Section I describes how to acquire the noise analysis software system and details data preparation and processing as well as the noise analysis calculations and methods. Section II is a detailed description of the software system itself. It will be useful to users interested in detailed installation instructions, and a complete description of the system directory structure and operations.

Section I: Introduction and Overview of Noise Analysis Methods

A new stand-alone system for analyzing data quality is now available to the seismology community allowing users to evaluate the long-term seismic noise levels for broadband seismic data in miniSEED format. The new noise processing software uses a probability density function (PDF) to display the distribution of seismic power spectral density (PSD) (PSD method after Peterson, 1993) and can be implemented against any broadband seismic data with well known instrument responses. The software system is currently running for routine noise monitoring at the United States Geological Survey's (USGS) Advanced National Seismic System (ANSS) National Operations Center (NOC) and at the Incorporated Research Institutions in Seismology's (IRIS) Data Management Center (DMC). For PDF plots from these two installations see:

http://geohazards.cr.usgs.gov/staffweb/mcnamara/ANSSPDFweb/ANSSPDFweb.html

and

http://www.iris.washington.edu/servlet/quackquery/

Software Availability

The new stand-alone software package is available on the world wide web (WWW) and on the USGS ANSS anonymous ftp server. To download a compressed tar ball of the software system, go to the following website and follow the downloading instructions.

http://geohazards.cr.usgs.gov/staffweb/mcnamara/Software/PDFSA.html

The download includes complete documentation on installing and running the noise processing system. It also includes several reference documents on interpreting the noise PDF plots (e.g. McNamara and Buland, 2004).

Noise Analysis System Overview

This noise processing system is unique in that there is no need to screen the data for earthquakes, system glitches or general data artifacts, as is commonly done in seismic noise analysis. Instead with this new analysis, system transients map into a low-level background probability while ambient noise conditions reveal themselves as high probability occurrences. In fact, examination of artifacts related to station operation and episodic cultural noise allows the user to estimate both the overall station quality and a baseline level of earth noise at each site. PDF noise plots are useful for characterizing the current and past performance of existing broadband sensors, for detecting operational problems within the recording system, and for evaluating the overall quality of data for a particular station. The advantages of this new approach include:

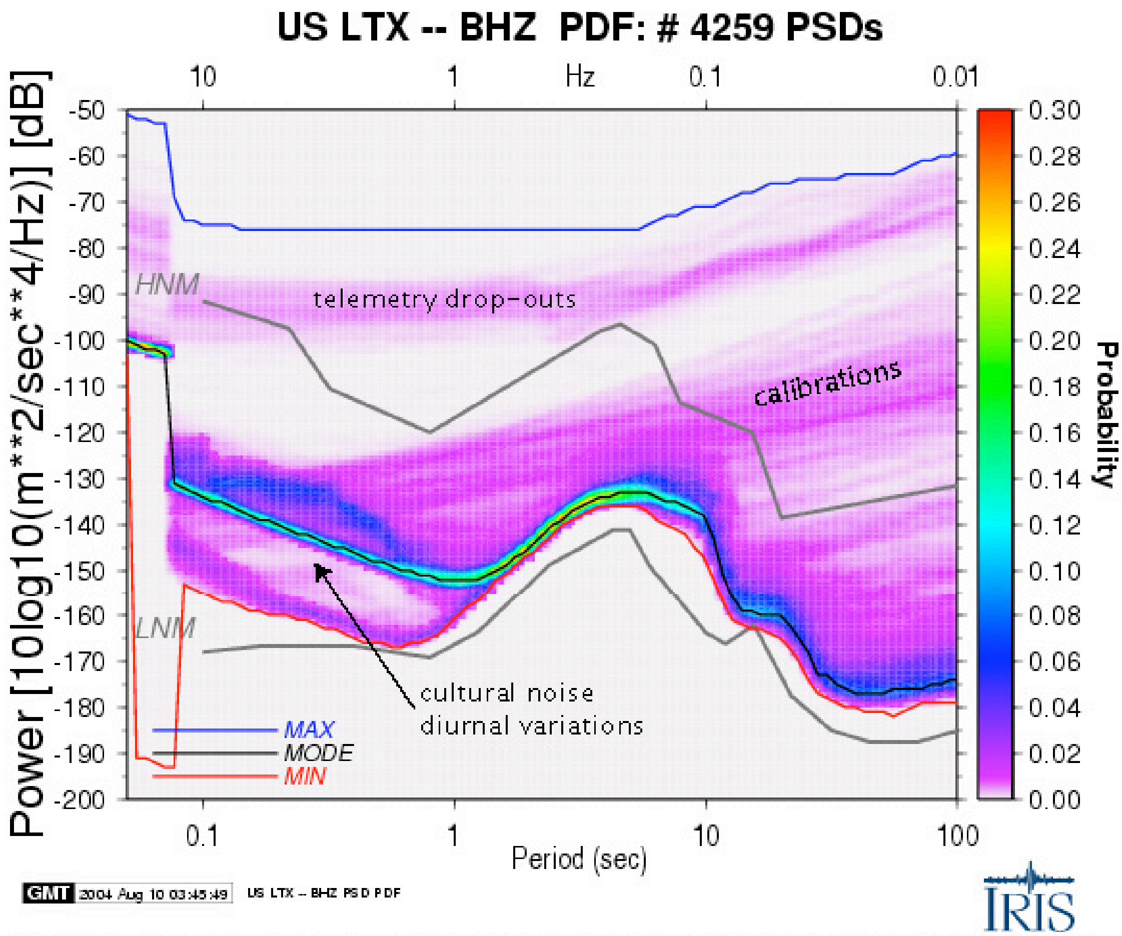
1) an analytical view representing the true ambient noise levels rather than a simple absolute minimum,

2) an assessment of the overall health of the instrument/station; and,

3) an assessment of the health of recording and telemetry systems.

Employing the algorithm used to develop the USGS Albuquerque Seismological Laboratory (ASL) low noise model (LNM; Peterson, 1993), we compute the power spectral density (PSD) for broadband data in the following manner. Hour-long, continuous, and over-lapping (50%) time series segments are processed. (N.B. There is no removal of earthquakes, system transients and/or data glitches.) The instrument transfer function is removed from each segment, yielding ground acceleration (for easy comparison to the LNM). Each hour-long time series is divided into 13 segments, each about 15 minutes long and overlapping by 75%, with each segment processed by: removing the mean; removing the long period trend; tapering using a 10% sine function; and transforming using an FFT algorithm (Bendat and Piersol, 1971). Segments are then averaged to provide a PSD for each one-hour time series segment. For each channel, raw frequency distributions are constructed by gathering individual PSDs in the following manner: binning periods in 1/8 octave intervals; and binning power in 1 dB intervals. Each raw frequency distribution bin is then normalized by the total number of PSDs to construct a Probability Density Function (PDF). The probability of occurrence of a given power at a particular period is plotted for direct comparison to the Peterson high and low noise models (HNM, LNM) (see Figure 1, LTX BHZ). Also computed and plotted are the minimum (red line), mode (black line), and maximum (blue line) powers for each period bin. A wealth of seismic noise information can be obtained from this statistical view of broadband seismic noise.

Figure 1



PDF analysis code by Daniel E. McNamara (USGS-NEIC), Ray Buland (USGS-NEIC) & Richard Boaz (private contractor).

Figure 1 is a PDF example for LTX BHZ, with some artifacts and signals identified. Station LTX - Lajitas TX, was instrumental in the original Peterson Low Noise Model (Peterson, 1993), however due to increased cultural noise (0.1-1s, 1-10Hz) the highest probability power levels (i.e. mode, black line) are now significantly higher than the Peterson low noise model (LNM). The minimum (red line) will approach the LNM <2% of the time indicating that the station minimum does not reflect actual ambient noise conditions across the whole spectrum. Instead, ambient noise conditions are better represented by the highest probability mode (black line).

Noise Analysis System Details

Data Preparation and Processing

The approach of this noise analysis method differs from many previous noise studies in that we make no attempt to screen the continuous waveforms to eliminate body and surface waves from earthquakes, or transients and instrumental glitches such as data gaps, clipping, spikes, mass re-centers or calibration pulses. These signals are included in our processing because they are generally low probability occurrences that do not contaminate high probability ambient seismic noise observed in the PDFs (see below for details). In fact, transient signals are often useful for evaluating station performance. Also, eliminating this event triggering and removal stage has the benefit of significantly reducing the PSD computation time by simplifying data pre-processing.

The algorithm used to develop the Albuquerque Seismological Laboratory (ASL) new low noise model (NLNM) and new high noise model (NHNM) (Peterson, 1993; Bendat and Piersol, 1971) is used to calculate PSDs for all stations in this study. The processing steps are detailed below.

Record length. Let a finite length seismic time series, $u(t)$, have N evenly sampled points at an interval of Δt. For our analysis, we parse continuous time series, for each station component, into one-hour (T_h=3600s) finite-length time series segments, overlapping by 50%, distributed continuously in time. Overlapping time series segments are used to reduce variance in the PSD estimate (Cooley and Tukey, 1965). For this example, we assume that for the broadband seismic data, each 3600s times series segment is sampled at 40 sample per second (sps), such that Δt=0.025s, for a total N=144,000 data points.

Pre-processing. The PSD pre-processing of each one-hour time segment consists of several operations. First, to significantly improve the Fast Fourier Transform (FFT) speed ratio, by reducing the number of operations, the number of samples in the time series, N, is truncated to the next lowest power of two, 2^{17}, leaving N=131,072 thereby reducing the series length such that T_h=3276.8s. Second, in order to further reduce the variance of the final PSD estimates, each roughly one-hour time series record is divided into 13 segments, overlapping by 75%, where the length of each new time series segment is now, $T_r=T_h/4$=819.2s with N=32,768=2^{15}. The sample size N is chosen on the basis of the longest period of interest, T_l, (lowest frequency, fl). In general, the record length, $T_r=N\Delta t$, is chosen such that it is ten times the longest resolvable period, T_l. Given this, $T_l, =1/f_l= T_r/10$=90s. The shortest period, Ts, (highest frequency, fh) is equivalent to the Nyquist folding frequency, fc=1/2Dt=20Hz, and is given by $Ts = 1/fc \leq 1/fh \leq$ 0.05s.

Third, in order to minimize long-period contamination, the data is transformed to a zero mean value and any long period linear trend is removed by the average slope method. If u_n are the data values in the time series $u(t)$ of length T_r and N samples, the data mean is given by:

(1)

$$u_{mean} = \frac{1}{N}\sum_{n=1}^{N} u_n$$

Long period trend, T_{lp}, is defined as any frequency component whose period is longer than the record length, T_r, and is defined as:

(2)

$$T_{lp} = \alpha_u\left(t - \frac{T_r}{2}\right)$$

where $0 \leq t \leq T_r$ and

(3)

$$\alpha_u = \frac{1}{\left(\frac{Tr}{3}\right)\left(\frac{2Tr}{3}\right)}\left[\int_{\frac{2Tr}{3}}^{Tr} u(t)dt - \int_{0}^{\frac{Tr}{3}} u(t)dt\right]$$

If trends are not eliminated in the data, large distortions can occur in spectral processing by nullifying the estimation of low frequency spectral quantities. Subtracting (1) and (2) from the original time series, $u(t)$, produces a new time series , $u(t)$, that has zero mean and long period trends removed: (4)

$$x(t) = u(t) - u_{mean} - T_{lp}$$

Fourth, to suppress side lobe leakage in the resulting FFT, a 10% sine taper is applied to the ends of the time series, *x(t)*. We define a new tapered time series, *y(t),* such that:

$$
\begin{aligned}
&y(t) = x(t) * \sin(p/2Tr * t) && 0 \leq t \leq Tr/10 \\
&y(t) = x(t) && Tr/10 \leq t \leq (Tr\text{-}Tr/10) \qquad (5)\\
&y(t) = x(t) * \sin(p/2Tr * (Tr\text{-}t)) && (Tr\text{-}Tr/10) \leq t \leq Tr.
\end{aligned}
$$

Tapering the time series has the effect of smoothing the FFT and minimizing the effect of the discontinuity between the beginning and end of the time series. The time series variance reduction can be quantified by the ratio of the total power in the raw FFT to the total power in the smoothed filter (1.142857) and will be used to correct absolute power in the final spectrum (Bendat and Piersol, 1973).

Power Spectral Density

The standard method for quantifying seismic background noise is to calculate the noise power spectral density (PSD). The most common method for estimating the PSD for stationary random seismic data is called the direct Fourier transform or Cooley-Tukey method (Cooley and Tukey, 1965). The method computes the PSD via a finite-range fast Fourier transform (FFT) of the original data and is advantageous for its computational efficiency.

The finite-range Fourier transform of a periodic time series *y(t)* is given by:

$$Y(f,T) = \int_0^{Tr} y(t) e^{-i2\pi ft} dt \qquad (6)$$

where the number of frequency amplitude estimates $nfft=(N/2)+1=16385$. For discrete frequency values, f_k, the Fourier components are defined as:

$$Y_k = \frac{Y(f_k,T)}{\Delta t} \qquad (7)$$

For , $f_k=k/NDt$ *when* $k = 1, 2, \ldots, N\text{-}1$.

Hence, using the Fourier components defined above, the total power spectral density estimate is defined as: (8)

$$P_k = \frac{2\Delta t}{N}|Y_k|^2$$

As is apparent from (8), the total power, P_k, is simply the square of the amplitude spectrum with a normalization factor of $2\Delta t/N$. The PSD process is repeated for each of the 13 separate overlapping time segments within the one-hour record. After all 13 segment PSD estimates are computed, powers are then averaged for $q=13$ separate time segments, where each time segment is of length T_r. The final smooth PSD estimate is given by:

$$P_k = \frac{1}{q}\left(P_{k,1} + P_{k,2} + \ldots + P_{k,q}\right) \tag{9}$$

where $P_{k,q}$ is the raw estimate at frequency f_k of the qth time segment. Due to segment averaging, the quantity P_k has $2q=26$ degrees of freedom giving a 95% level of confidence that the spectral point lies within –2.14dB to +2.87dB of the estimate (Peterson, 1993).

At this point we correct P_k for the 10% sine taper applied earlier in the processing such that $P_k = P_k*1.142857$ and then deconvolve the seismometer instrument response by dividing the PSD, P_k, estimate by the instrument transfer function to acceleration, in the frequency domain. Finally we convert the smoothed PSD estimate into decibels (dB) with respect to acceleration $(m/s^2)^2/Hz$, for direct comparison to the NLNM,by:

$$P_k = 10*\log_{10}(P_k). \tag{10}$$

Limitations. The PSD technique described above provides stable spectra estimates over a broad range of periods (0.05-90s) however, it suffers from poor time resolution due to the long transforms and requires hundreds to thousands of hours of data to compile good statistics for the PDFs. For better resolution at shorter periods, a larger number of shorter records should be analyzed. Future work will investigate methods to improve resolution of higher frequencies.

Probability Density Functions

Our goal is to get a sense of the true variation of noise at a given station. We do this by generating seismic noise probability density functions (PDFs) from the PSDs processed using the methods discussed in the previous section. In order to adequately sample the PSDs, full octave averages are taken in 1/8 octave intervals. This procedure reduces the number of frequencies by a factor of 169 from *nfft*=16,385 to 97. Thus, power is averaged between a short period (high frequency) corner, T_s, and a long period (low frequency) corner of $T_l=2*T_s$, with a center period, T_c, such *that* $T_c=sqrt(T_s*T_l)$ is the geometric mean period within the octave. The geometric means are then evenly spaced in log space. The average power for that octave, period range from T_s to T_l, is stored with the center period of the octave, T_c, for future analysis. T_s is then incremented by one 1/8 octave such that $T_s = T_s*2^{0.125}$, to compute the average power for the next period bin. T_l and T_c are recomputed, powers are averaged within the next period range T_s to T_l, and the process continues until we reach the longest resolvable period given the time series window length of the original data, $T_r/10$ (Figure 2). This process is repeated for every one-hour PSD estimate, resulting in thousands of smooth PSD estimates for each station-component. Powers are then accumulated in 1 dB intervals to produce frequency distribution plots (histograms), for each period (Figure 3).

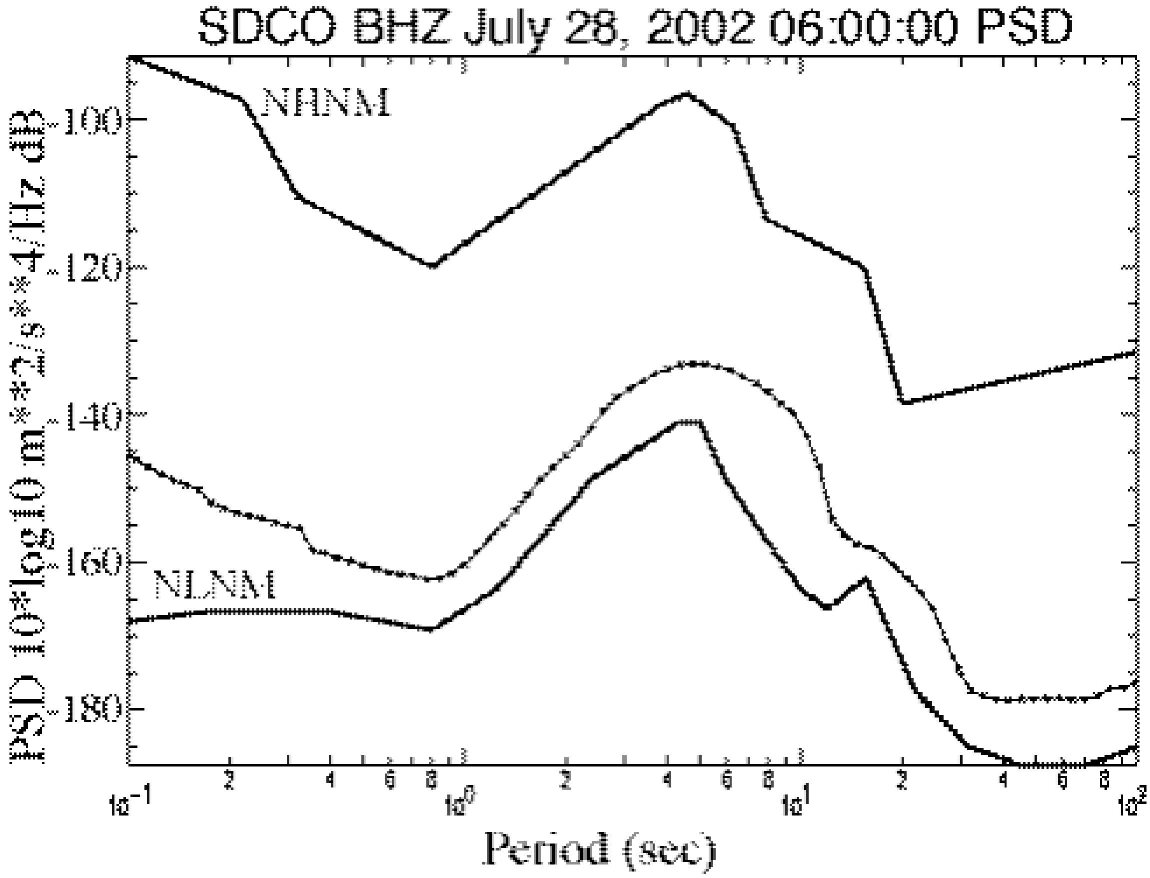


Figure 2: SDCO BHZ July 28, 2002 06:00:00 PSD. Powers are averaged over full octaves in 1/8 octave intervals. Center points of averaging shown.

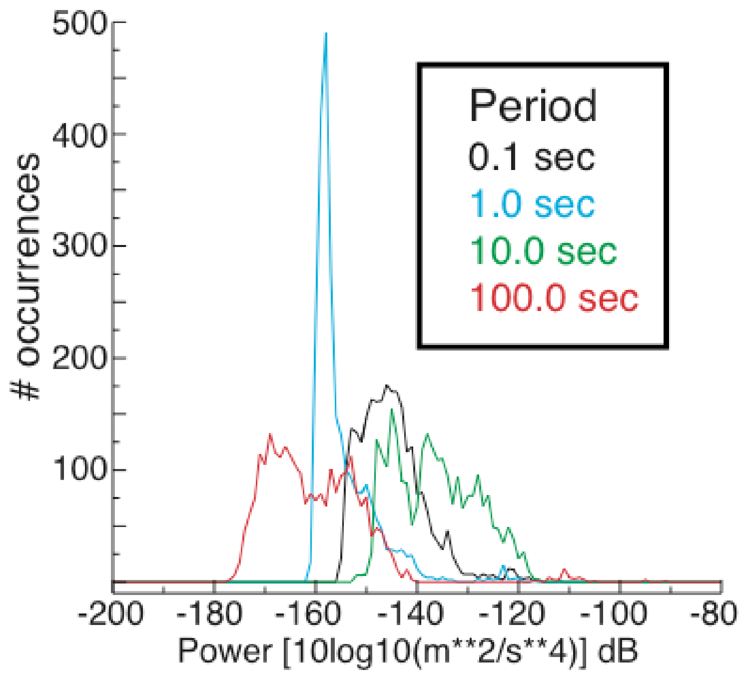


Figure 3: Histograms of powers, in 1dB bins, at four separate period bands for station AHID BHZ.

The next step is to plot the distribution of powers per period, as observed in figure 3, using a probability density function (PDF). The PDF, for a given center period, T_c, can be estimated as:

$$P(T_c) = N_{PTc}/N_{Tc} \qquad (11)$$

where N_{PTc} is the number of spectral estimates that fall into a 1 dB power bin, P, with a range from –200 to –80 dB, and a center period, T_c. N_{Tc} is the total number of spectral estimates over all powers with a center period, T_c. We then plot the probability of occurrence of a given power at a particular period for direct comparison to the high and low noise models (Figure 1 and 4) (Peterson, 1993). We also compute and plot the minimum, mode and maximum powers for each period bin. A wealth of seismic noise information can be obtained from this statistical view of broadband PDFs, as discussed in the following section.

Characterizing Sources of Noise and Signal in the PDFs

Cultural Noise. The most common source of seismic noise is from the actions of human beings at or near the surface of the Earth. This is often referred to as "cultural noise" and originates primarily from the coupling of traffic and machinery energy into the earth. Cultural noise propagates mainly as high-frequency surface waves (>1-10Hz,1-0.1s) that attenuate within several kilometers in distance and depth. For this reason cultural noise will generally be significantly reduced in boreholes, deep caves and tunnels. Cultural noise shows very strong diurnal variations and has characteristic frequencies depending on the source of the disturbance (Figures 1 and 4). Another source of noise with a strong diurnal is from thermal instabilities. Heating during the day and cooling at night can cause ground fluctuations that induce tilt and long period noise.

Earthquakes. Our approach differs from many previous noise studies in that we make no attempt to screen the continuous waveforms to eliminate body and surface waves from naturally occurring earthquakes. Earthquake signals are included in our processing because they are generally low probability occurrences even at low power levels (small magnitude events) compared to the ambient conditions at the seismic station. We are interested in the true noise that a given station will experience, thus we include all signals. For example, including earthquakes tells us something about the probability of teleseismic signals being obscured by small local events as well as various noise sources. Large teleseismic earthquakes can produce powers above ambient noise levels across the entire spectrum and are dominated by surface waves >10s, while small events dominate the short period, <1s. Earthquakes are observed in the PDFs as low probability smeared signal at short and long periods (Figure 4).

System Artifacts. Since we make no attempt to screen waveforms for system transients such as data gaps and sensor glitches, the PDF plots contain numerous system generated artifacts that can be very useful for network quality control purposes. We have attempted to determine the source of several coherent, high power, low probability noise artifacts in the PDF plots. Several artifacts in the PDFs are easily explained and may be useful to the network operator. For example, data-gaps (due to telemetry drop-outs) and automatic mass re-centers (necessitated by "drift" in sensor mass position) are easily identifiable in the PDFs. Should the probability of mass re-centering and/or telemetry drop-outs drastically increase, a remote network operator could readily diagnose the problem (Figures 1 and 4). Additional features and artifacts observed in the PDFs are described online at: http://geohazards.cr.usgs.gov/mcnamara/PDFweb/Noise_PDFs.html and in McNamara and Buland (2004).

Summary and Conclusions: Section I

We have presented a new method for more realistically evaluating ambient seismic noise levels at a station based on the power spectral density methods used to generate the NLNM of Peterson (1993). This approach is useful because seismic stations exhibit considerable variations in noise levels as a function of time of day, season, location and installation type. This type of information is not readily observed when only minimum noise levels are analyzed. The results of this type of background noise analysis are useful for characterizing the performance of existing stations, for detecting operational problems, and should be relevant to the future siting of broadband seismic stations. Details on software system installation and operations will be discussed in Section II.

References

Bendat, J.S. and A.G. Piersol (1971). Random data: analysis and measurement procedures. John Wiley and Sons, New York, 407p.

Cooley, J.W., and J. W. Tukey (1965), An algorithm for machine calculation of complex Fourier series, *Math. Comp.*, 19, 297-301.

McNamara, D.E. and R.P. Buland, Ambient Noise Levels in the Continental United States, Bull. Seism. Soc. Am., 94, 4, 1517-1527, 2004.

Peterson, J., Observation and modeling of seismic background noise, U.S. Geol. Surv. Tech. Rept., 93-322, 1-95, 1993.

Wessel, P. and W. Smith, Free software helps display data, *EOS*, 72, 445-446, 1991.

Acknowledgements

The algorithm and initial software were first developed by Dan McNamara and Ray Buland, with contributions from Harold Bolton and Paul Earle, at the United States Geological Survey (USGS) as a part of the ANSS IDCC quality control (QC) system. Further development, supported by IRIS through funds it receives from the National Science Foundation (NSF) allowed for Richard Boaz to develop the system for implementation against the real-time BUD dataset and the real-time data stream at the USGS ANSS NOC. Additional support was provided by the USGS to produce the stand-alone software package discussed in this report. PDF plots are generated with the GMT plotting tools (Wessel and Smith, 1991). Appropriate citation for this noise analysis method is McNamara and Buland (2004) (see references).

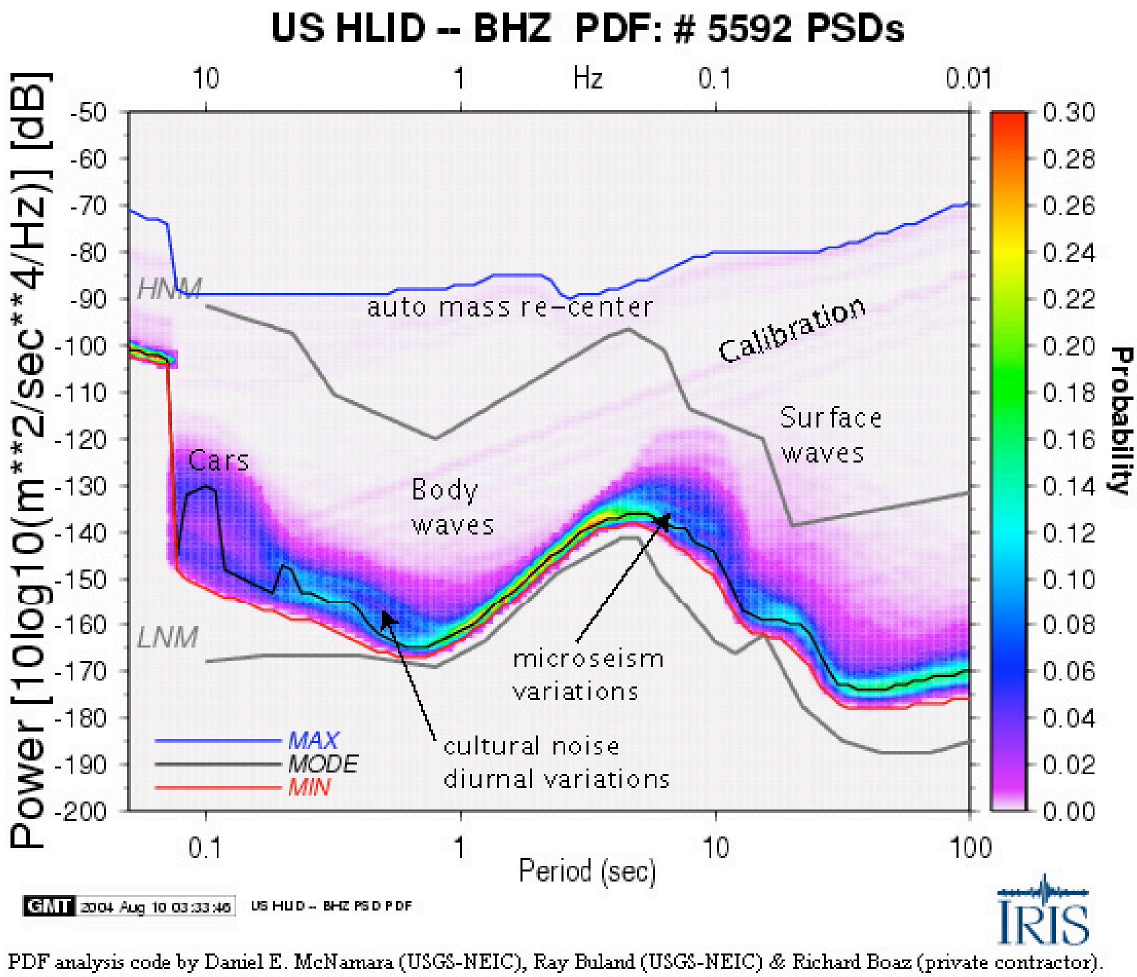


Figure 4: HLID - Typical ANSS station ~10km from Hailey Idaho. Automobile traffic along a dirt road only 20 meters from station HLID creates a 20-30dB increase in power at about 0.1 sec period (10Hz). This type of cultural noise is observable in the PDFs as a region of low probability at high frequencies (1-10Hz, 0.1-1s). Body waves occur as low probability signal in the 1sec range while surface waves are generally higher power at longer periods. Automatic mass re-centering and calibration pulses show up as low probability occurrences in the PDF.

Section II: System Description and Installation Instructions

Table of Contents

PDF Analysis System – Stand Alone Installation

Introduction

Following from the successful implementation of the PDF Noise Analysis System, both at the IRIS DMC in Seattle, WA, and at the NEIC in Golden, CO, it is desired to provide the system to the seismic community at large in a stand-alone form. This, to allow other users of the seismic community the opportunity to perform their own analyses against data sets not being held by either of these two data centers.

Quick Install

If the time required to read and understand this document in totality is unavailable (but you'd like it installed and working as quickly as possible), you must at least read the sections **System Configuration**, **System Compilation and Installation**, and **PDF System Execution** and follow the steps outlined there. Where problems occur, be certain to consult the other various sections of this document that may provide further information to solve your issue.

Audience

This document is intended for all users of the siesmic community with an interest in producing noise analyses of seismic data following the algorithm laid out by McNamara and Buland of the USGS ANSS NOC of Golden, Co.

Scope

This document is limited to the technical aspects of the **PDF Analysis System**: installation, configuration and execution. As such, it does not treat the functional aspects of the system: methodologies, algorithm, philosophy, interpretation possibilities, usage of results, etc. For a complete discussion of these and more, please consult the various documents listed below.

Acknowledgments

The following parties have significantly contributed to the development of this system and are hereby acknowledged thus:

Party	**Contribution**
Ray Buland and Daniel McNamara (of USGS NEIC, Golden, CO)	Provided the original algorithm and proof-of-concept implementation
USGS NEIC	Provided the funds for original development of algorithm.
NSF	Provided funds for original system development of generic implementation at the IRIS Data Management Center (Seattle, WA).
IRIS	Sponsored the development of the generic implementation at the DMC.
Bruce Weertman (of IRIS)	Responsible for integration of the PDF system within the IRIS DMC's Quack framework.

Authorship

Both this document and the PDF analysis system itself was written by Richard Boaz (of Boaz Consultancy: http://www.boazconsultancy.com) and Dan McNamara (USGS). Any and all comments and/or bug reports are welcome and are encouraged to be forwarded to riboaz@xs4all.nl.

References

The following table provides various references which may be of interest to the reader:

Description	Name	Location
Original Abstract (Adobe pdf)	Ambient Noise Levels in the Continental United States	PDF Stand-Alone distribution docs directory
Power Point Presentation	Noise Based Detection Method for the ANSS	PDF Stand-Alone distribution docs directory
Discussion Paper (Adobe pdf)	Determining True Global Ambient Noise	PDF Stand-Alone distribution docs directory
PDF Analysis Interpretation (html document)	Ambient Noise Probability Density Functions	PDF Stand-Alone distribution docs directory
PDF Analyses at the USGS NEIC	USGS/ANSS Noise Monitor	http://geohazards.cr.usgs.gov/staffweb/mcnamara/ANSSPDFweb/ANSSPDFweb.html
PDF Analyses at the IRIS DMC	DMC QUACK Information Query	http://www.iris.washington.edu/servlet/quackquery/
PDF Analyses at the IRIS DMC (US Array)	DMC QUACK Information Query	http://www.iris.washington.edu/servlet/quackquery_us

Description

Quite simply, the PDF Analysis system is comprised of three separate processing components:

1. An analysis program (written in C), responsible for producing analysis statistics for a single channel;
2. A shell program (using GMT) to convert the analysis results produced in step 1 to a plot, in the form of a postscript format file;
3. Image manipulation (using ImageMagick) commands to convert the postscript file created in step 2 to an actual graphical image (.png format).

Execution is provided in the form of a shell script per channel to analyze, responsible for calling each of these components in turn (see section **PDF System Execution** below for details).

Requirements

Hardware

No specific hardware requirements exist, per se. The program will execute on any platform supporting a C compiler in addition to the other software requirements listed below.

Depending on which compile time output option is chosen (please see section **System Compilation and Installation: Compilation: Compile Options** for a complete discussion of these options and their effects), disk storage requirements are approximately the following (per channel analyzed):

Output Option	Maximum Disk Storage Requirement
No Daily or Hourly .bin output	5 Mb
Only Daily .bin output	15 Mb
Both Daily and Hourly .bin output	50 Mb

Software

The following table defines the software dependencies currently en force:

Software	Version	Description	Available At
C Compiler	User preference	Compiler (program developed under gcc)	http://gcc.gnu.org/
Scripting	Bash shell	Scripting tools	Local machine executing analysis
GMT	Latest available	Plotting tool	http://gmt.soest.hawaii.edu/
ImageMagick	Latest available	Image manipulation tool	http://www.imagemagick.org/

PDF Source Code Organization

The following table defines the directories and files which make up the source tree of the PDF Analysis System:

Directory/File	Description
PDF	Root system directory
PDF/PROD	Production directory containing production relevant files
PDF/PROD/bin	Directory containing shells and executables,
PDF/PROD/script	Directory containing executable scripts
PDF/PROD/support	Directory containing all necessary production support files
PDF/PROD/helper	Directory containing helper scripts (system mgmt, etc.)
PDF/src	Directory holding all source code: • PDF analysis program • GMT plotting script • Execution scripts
PDF/src/v*x.x.x*	Directory holding all source code for version *x.x.x* of the system
PDF/src/ v*x.x.x*/analysis	Source code directory of analysis program (C code)
PDF/src/ v*x.x.x*/analysis/mseed	Miniseed data file reader source code - as library to main()
PDF/src/ v*x.x.x*/analysis/resp	Instrument response interpreter source code - as library to main()
PDF/src/ v*x.x.x*/GMT	Directory holding GMT source code - scripts and support files
PDF/src/ v*x.x.x*/script	Directory holding execution scripts

Input and Output Files

Input

The following table defines the directories and files which are required input, see sections **System Configuration** and **PDF System Execution** for full description of specification and use:

Directory/File	Description
Data Directory	Directory holding the miniseed data files to be analyzed. **N.B.** All data files requiring analysis as part of a single execution must reside in this single directory.
Miniseed Data Files	Files to analyze, miniseed format only.
Analysis Directory	Directory holding all output files. See section **Output** for a complete description.
Response File Directory	Directory holding response files for channels being analyzed. See section **System Configuration** for a complete discussion on set-up.
RESP.*NTW.STN.LOC.CHN*	The file holding the response information for the instrument and channel. This must be formatted as for input to the evresp() function (format as produced by the rdseed program). Where: *NTW* is the network name *STN* is the station name *LOC* is the location identifier *CHN* is the channel identifier

Output

The following table defines the directories and files which are created in the course of the PDF Analysis execution. All are located as subdirectories to the analysis directory defined in the section **Input** above and are automatically created in the course of execution. Please consult **Appendix I – File Formats** for a detailed description of their contents.

Directory/File	**Description**
NTW.STN.LOC.CHN.png	Graphical representation of analysis.
Y*yyyy*	Directory holding daily PSD .bin files, by year Where: *yyyy* is the year
Y*yyyy*/HOUR	Directory holding the hourly PSD .bin files
LOG	Directory holding the various log files created during the course of execution.
wrk	Directory holding various work files
Y*yyyy*/D*jjj*.bin	Files holding individual day's PSD analysis results (currently unused, for future use). Where: *jjj* is the julian day
Y*yyyy*/HOUR/hour.idx	Index file to H*jjj*.bin file.
Y*yyyy*/HOUR/H*jjj*.bin	Files holding individual hour's PSD analysis results (currently unused, for future use)
LOG/*NTW.STN.LOC.CHN*.log	Log file of analysis program.
LOG/plotGMT.log	Log file of GMT plotting program.
LOG/convert.log	Log file of ImageMagick convert program, nothing output for normal execution.
LOG/*NTW.STN.LOC.CHN.yyyy.jjj*.err	Analysis program error file, by year and julian day
LOG/PDFanalysis.skp	File listing those days when problems occurred, information only
wrk/PDFanalysis.bin	Cumulative dB-based .bin file, results to graph are contained here
wrk/PDFanalysis.inf	Information file holding various analysis settings
wrk/PDFanalysis*SR*.bin	Cumulative period-based .bin file. Where: *SR* is the sample rate of the channel
wrk/PDFanalysis*SR*.inf	Information file as before, sample-rate specific
wrk/PDFanalysis.sts	File holding various statistics for analysis results, input to GMT
wrk/PDFanalysis.ps	GMT postscript file output, deleted upon conversion to .png file.
wrk/pdf.grd	GMT temp file, deleted upon completion of GMT step.

System Configuration

Configuration of the PDF system amounts to the setup of various directories and script variables. This section lays out these requirements for the PDF system setup to result in a successful installation and subsequent execution. Failure to define these precisely as described herein will result in a non-functioning system.

Appendix II provides a checklist for each parameter and variable which must be defined as part of system setup. Please print, define the values accordingly and supply them in their proper location.

Data Directories

MiniSeed Data Directory and Files

A directory is required to contain the miniseed data files to be analyzed. This directory and the miniseed data files themselves must adhere to the following:

1. All miniseed data files representing a single channel's worth of waveform data, for all time, must be contained within the same directory.
2. All miniseed data files must contain exactly (or as close to) one day's worth of data, from 00:00 hours to 24:00 hours.
3. The directory structure must conform to the following conventions:

   DATAROOT/NTW/STN

   Where

DATAROOT	is the root directory of the miniseed data files (script variable of such specified below)
NTW	is the name of the network
STN	is the name of the station

4. The name of the miniseed file itself must conform to the following naming convention:

   STN. NTW.LOC.CHN.yyyy.jjj

   Where

STN	is the name of the station
NTW	is the name of the network
LOC	is the location identifier
CHN	is the channel identifier
yyyy	is the year of the data file
jjj	is the julian day of the data file

   (N.B. Where no location identifier exists, field should be null. This would render, for example, a filename for station ATKA and network AK as: ATKA.AK..BHE.2004.261)

Assuming your directory structure and miniseed data files do not naturally conform to these requirements, this directory structure and filenaming convention can be easily accommodated for through the following:

- Create the fixed directory structure itself: *DATAROOT/NTW/STN*
- For each miniseed data file, create softlinks (ln –s) to the actual/real miniseed data files such that the naming convention above is adhered to.

Further, this can be automated via a script rendering this requirement as trivial as possible. Please see the script linkMseed.US (located in pdf/PROD/helper/linkmseed) for an example and modify as necessary.

N.B. Because the filenaming convention uniquely identifies the channel of data, this directory may contain all miniseed data file for all channels of a station, i.e., it is not necessary to create separate directories for each channel, rather, a separate directory only for the station itself and containing the miniseed data files for all channels.

Response File Directory

A directory must exist containing all response files used to deconvolve the signal back to absolute ground motion in the course of analysis. This directory and the files themselves must adhere to the following:

1. The directory itself may be specified as per user desires/requirements, no specific directory structure requirement exists. The directory holding these response files must be specified in two places: in the script variable RESPDIR (see section **Script Vaiables** below), and within the PDFuser.h file of the PDF analysis program source code (see section **Source Code Header File Modification** below).
2. The filename of the response file itself must conform to the following naming convention:

   RESP.*NTW.STN.LOC.CHN*

   Where

RESP	is exactly as specified: RESP
NTW	is the name of the network
STN	is the name of the station
LOC	is the location identifier
CHN	is the channel identifier

   (N.B. This naming convention follows from the response file output generated by the rdseed program. And as before, where no location identifier exists, field should be null.)
3. The internal format of the response file information must conform to the format produced by the rdseed program, subsequently readable by evresp().

Web Directory

A directory must be created used to collect all .png files created during the course of execution. The .png files themselves are contained in the analysis directory for the channel being analyzed, making collective viewing annoying since all are held within disparate directories. This annoyance is alleviated through the existence of this directory.

Create a directory for these to be contained in and define this location in the **.vars-user** file. With this directory, the last action in the course of analysis is for a softlink to be created in this directory pointing to the .png file found in the analysis directory.

Additionally, if it is desired to publish the results, it is this directory that can be made available to the web in whatever manner/means appropriate.

Script Variables

The following script variables are installation-specific and must be pre-defined by the user and provided in the shell script file **.vars-user** (located in directory PDF) before the system can be installed. Failure to do so will result in a non-functioning system.

Script Variable Name	**Description**
PDFROOT	Root directory of PDF analysis system (directory holding the .vars-user file)
WEBDIR	Directory of collected .png files
RESPDIR	Directory holding response files
DATAROOT	Root directory of miniseed data files (parent to *NTW*/*STN*)
STATSROOT	Root directory of PDF analysis results/statistics
GMTROOT	GMT installation root directory
IMROOT	ImageMagick installation root directory

Source Code Header File Modification

The sole configuration requirement within the source code of the PDF analysis program is the following #define parameter to be specified: (N.B. needless to say, this must be the same as defined as part of the Script Variables above.)

#define parameter	**Description**	**Location**
#define RESPDIR	Directory holding response files, inside quotes "".	PDF/src/v*x.x.x*/analysis/PDFuser.h

System Compilation and Installation

Compilation

Compilation of the PDF Analysis program employs straightforward C/Unix standards, i.e, a **C compiler** and **make**. In addition to the analysis portion of the program, there are two subdirectories of libraries requiring compilation as well. As such, a script is provided that will traverse each of these subdirectories, making the dependent libraries in turn. This script is located in the PDF Analysis source directory and conforms to the following invocation specifications:

makesh [*clean* / *all*]

where

clean will execute **make clean**, removing all dependant libraries and object files.

all will execute **make all** in each directory of the PDF analysis program, creating all dependant libraries and object files necessary to ultimately link the PDF analysis executable.

Alternatively, the program may be built when installing the system as a whole, alleviating the need to compile and link by hand. Please see the section **Installation** below for details.

Compiler Options

Two compile-time options exist for the PDF Analysis program. Namely, defining whether or not daily and/or hourly PSD information is output. (Please see section **Requirements: Hardware** for detailed overall disk storage requirements.)

With daily PSD information output, cumulative .bin files are generated for each day analysed (amounting to ~30Kb/day/channel analysed).

With hourly PSD information output, .bin files are generated for each hour analysed (amounting to ~100Kb/day/channel analysed).

The system is delivered, by default, to output both daily and hourly .bin files. Output of this data is anticipated to be used in future versions of the software, such that existence of these files will allow PDFs to be produced for specific user-defined time periods. For example, a PDF graph representing only the months of January thru March; or a PDF graph representing all months but only between the hours of 6AM and 6PM.

If it is anticipated that these more specific sorts of analyses will be of interest, no action is required, both daily and hourly .bin files will be generated.

If this is not desired, or disk space is an issue, both daily and hourly .bin file generation may be suppressed. The following table defines these compile time options:

Compiler Option	Effect
-DNO_DAILY_PSD	No daily PSD .bin files output
-DNO_HOURLY_PSD	No hourly PSD .bin files output

Either or both (they are mutually independent) of these options can be specified in the **CFLAGS** section of the **Makefile** for the main PDF Analysis program. The resulting executable will subsequently **NOT** output incremental PSD information.

N.B. Since these are compiler options, these settings have a system-wide influence, i.e., these options **cannot** be implemented on a per channel basis. (One way around this, however, would be to install more than a single system.)

Installation

Installation is provided via the shell script **installPDF** located in the directory PDF and provides for the following functionality:

1. optionally compiles the PDF Analysis program, and
2. copies all relevant files to the PROD directory.

And conforms to the following usages:

command: *installPDF –h*
output: Usage: install [-h] [make] version#
description: prints the usage for the command.

command: *installPDF v1.1*
output: Copying v1.1 executables and support files to PROD dir…
description: installs all relevant executables, scripts and support files for *version#* to the PROD directory structure. (N.B. command line argument *version#* must be as specified in the PDF source directory structure.)

command: *installPDF make v1.1*
output: Compiling v1.1 PDF Analysis program…
Copying v1.1 executables and support files to PROD dir…
description: as for command *installPDF v1.1*, however, cleans and compiles the PDF analysis program before copying and installing to the PROD directory structure (recommended for first install since no object files exist as part of delivery).

PDF System Execution

System execution comes in the form of two scripts, **executePDF** and **PDFscript** (both located in PDF/PROD/bin).

PDFscript is a shell script template used to create the individual channel-specific execution script, this script ultimately responsible for the PDF analysis execution of a specific channel.

The **executePDF** script executes all channel-specific scripts located in PDF/PROD/script in turn.

Channel-Specific Shell Script

Execution of the PDF Analysis System is provided in the form of a shell executable script (**PDFscript**) responsible for carrying out the three steps of execution described in section **PDF Analysis System Overview: Description**. This execution script is created by replacing various strings in the generic file PDFscript with execution-specific values, thus creating a unique script for each channel to be analyzed.

This channel-specific executable shell can be easily created using the following shell script command:

> **makePDFscript** *NTW STN LOC CHN*

where

NTW	is the network name
STN	is the station name
LOC	is the location identifier (use -- for no location)
CHN	is the channel identifier

The will create the channel-specific script to be executed, named *NTW.STN.LOC.CHN*.sh and saved to the directory PDF/PROD/script. In addition, the analysis directory will also be created if it does not exist (assuming the STATSROOT directory exists).

Once this script has been created for a specific channel, it can be simply repeatedly executed (daily, weekly, monthly, as desired) to update the analysis results.

Overall Execution

Executing the script **executePDF** will result in all scripts located in PDF/PROD/script to be executed in turn. Specifically, it will execute all files having ".sh" as their filename suffix. Thus, individual analyses can be turned on and off simply by renaming the suffix of the executable script in question.

A simple logfile of **executePDF**, detailing the channels analyzed, is generated and written to the file PDF/PROD/LOG/PDF.log.

Further, this process may be automated using the UNIX **crontab** command. At specified times, merely execute the **executePDF** script and all analyses will be performed and updated.

Execution Features

Please note the following features of the PDF analysis system:

1. Analysis is performed against all data files found in the specified data directory only up to and until two days prior to analysis execution date. This allows for systems where data availability can suffer up to two days of latency.

2. The program does cross the day boundary to analyze the last hour of data held within the miniseed files. As such, the last file identified for analysis is not fully analyzed; it is treated in subsequent executions.
3. When crossing the day boundary, program assumes data is coincident if ending time and starting time of respective miniseed files differ by less than one sample (1) of time. Where data is identified not to be coincident, an error message is output to the channel-specific log file.

Error Processing

Error handling is very much dependent on the type of error encountered. The following table lists the major errors that may be encountered, how each is handled, and suggested follow-up action.

Error	Type	How Handled	User Follow-up
Response File not found	Fatal	Analysis execution suspended; error message written to Log file	Provide proper response file, verify naming convention is adhered to.
Response Information not found	Fatal	Analysis execution suspended; error message written to Log file	Provide file containing response information for appropriate date/time range, verify file format is adhered to.
Error reading miniseed data file	Non-fatal	Analysis execution skips this day of data; error message written to day-specific error file located in LOG directory of analysis output.	Determine if miniseed data file can be repaired.
Internal Processing Error	Fatal	Analysis execution suspended	Contact riboaz@xs4all.nl with all relevant information
No files ever found to analyze	Non-fatal	Program successfully executes but nothing analyzed	Verify miniseed directory structure and filenaming conventions are adhered to.
Unable to create or access directories	Fatal	Analysis execution suspended	Confirm existence and access permissions of directory in question.

Release Notes

Current Limitations

The limitations are currently defined to be:

1. unable to analyze long period channels, limited to 20 samples/sec or more;
2. unable to provide analysis for user-defined time periods, only analysis of all data available is currently provided for;
3. output provided to end-user currently limited to .png graphical file format;
4. unable to analyze any data prior to the last day analyzed. This means that the program cannot fill in gaps nor replace the results of previously analyzed data. This will be treated in a future release.

Version Control

This section defines the current and historical releases of the PDF Analysis System.

Version 1.1

Release Date: 29-October-2004

Modifications

1. Stand-alone version created and made available for general release.

Appdendix I – File Formats

This appendix defines the formats of the various files produced by the PDF analysis system.

Djjj.bin File

Definition: Cumulative db-based .bin file holding **daily** PSD analyses for julian day *jjj*.
Directory: Y*yyyy*

Internal Format:

- Data Format: ASCII
- Individual lines each defining:

FREQ POWER #HITS

Where:

FREQ	is the frequency (in Hz)
POWER	is the power bin (in dB)
#HITS	is the number of times

Hour.idx File

Definition: Index file to H*jjj*.bin file, index defined by julian day and *HH:MM* start time of PSD.
Directory: Y*yyyy*/HOUR

Internal Format:

- Data Format: ASCII
- Individual lines each containing:

JDAY HH:MM REF

Where:

JDAY	is the julian day
HH:MM	is the hour and minute start time of the PSD
REF	is the reference identifier, for accessing/extracting from the H*jjj*.bin file

Hjjj.bin File

Definition: Cumulative db-based .bin file holding **hourly** PSD analyses for julian day *jjj*.
Directory: wrk

Internal Format:

- Data Format: ASCII
- Individual lines each containing:

REF FREQ POWER

Where:

REF	is the reference identifier from the hour.idx file
FREQ	is the frequency (in Hz)
POWER	is the power bin (in dB)

PDFAnalysis.bin File

Definition: Cumulative db-based .bin file holding **overall** PSD probabilities for julian day *jjj*.
Directory: wrk

Internal Format:

- Data Format: ASCII
- Individual lines each defining:

FREQ *POWER* *PROB*

Where:

FREQ is the frequency (in seconds)
POWER is the power bin (in dB)
PROB is the normalized (to probability) number of hits

PDFAnalysis.inf File

Definition: Information file containing various settings/values pertaining to analysis.
Directory: wrk

Internal Format:

- Data Format: ASCII
- Individual lines each defining:

VALUE :SETTING

- With the following SETTINGs currently being provide for, appearing in the following order:

SETTING	Definition
Analysis Start Date	Start day of the analysis (format: *YYYY:JJJ*)
Analysis Stop Date	Stop day of the analysis (format: *YYYY:JJJ*)
Total Number of Days	Total number of days analyzed
Total Number of PSD's	Total number of PSD's making up the analysis
Total Number of Problem Days	Total number of days encountering a problem (information only)
SAMPLE RATE	Sample rate of the channel
NETWORK	Network name
STATION	Station name
LOCATION	Location identifier
CHANNEL	Channel identifier
NYQUIST	Nyquist value for this analysis

PDFanalysis.sts File

Definition: File holding various statistics for this analysis.
Directory: wrk

Internal Format:

- Data Format: ASCII
- Individual lines each defining:

FREQ *MIN* *AVE* *50%* *90%* *MAX* *MODE*

Where:

FREQ is the frequency in question (in Hz)
MIN is the minimum PSD value
AVE is the average PSD value

50% is the 50th percentile PSD value
90% is the 90th percentile PSD value
MAX is the maximum PSD value
MODE is the mode PSD value (most common)

PDFAnalysisSR.bin File

Definition: Cumulative db-based .bin file holding **overall** PSD for julian day *jjj*.
Directory: wrk

Internal Format:

- Data Format: ASCII
- Individual lines each defining:

FREQ POWER PROB

Where:

FREQ is the frequency (in Hz)
POWER is the power bin (in dB)
PROB is the number of hits for this bin